# MODERN VIEWS OF MATTER

OLIVER J. LODGE, *Liverpool.*

ASKED to write on the subject of Physics and Physiology, I essayed the task, and attempted to enter upon the possible mechanism and detail of nerve transmission, and the like; for it is clear that all nervous action has an electrical concomitant; and an examination of the question whether the connection between the electro-motive force and the nervous impulse be accidental or essential, and what is the mechanism of transmission, is clearly an important enquiry.

Physiologists of late years have made so much use of delicate electrical instruments, they have directed so much attention to electrical manifestations in muscle and nerve, and these electrical effects have proved so useful a test and record of nerve phenomena, that it is just possible in some instances that they may have acquired an aspect of over-great importance, that they may be thought of as the real phenomena themselves, instead of possibly only an accompaniment of relative minuteness and insignificance,—a secondary adjunct which is only made manifest because of the extreme delicacy of modern electrical instruments of research.

The important thing to attend to about a nerve is the method whereby the impulse travels from place to place, the processes occurring in its substance which fit it for its purpose. What is
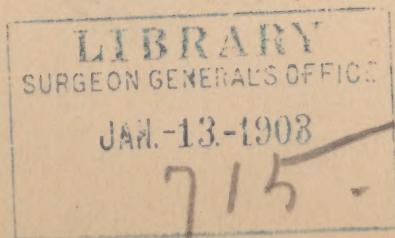
clear is that this is not of the nature of an ordinary electric current, not even of an electric current in a bad conductor.

A message can be delayed to any extent by replacing a telegraph wire by a bit of wet string, but the process of signalling through a few yards of string or cotton, with a high electro-motive force to drive the signal, is not analogous to the process of signalling through a nerve; for the nervous impulse has a definite velocity, slow no doubt but definite, and at any instance at a given place it has either arrived or not arrived. The disturbance passes a given place at definite speed, and with an intensity the same all along and almost proportional to the initiating stimulus.

But with an electric pulse travelling along the string it is different; that has no definite speed of travel, it is of the nature of a diffusion. Its detection at a distant end is simply a question of the sensitiveness of the receiving instrument. If that were infinitely sensitive it would be detected at once, or at least with the speed of light; whereas if the receiver will not respond except to a considerable potential, or a considerable current, it may not be able to respond at all; or supposing that it is able to respond ultimately, the lapse of time before it responds may be anything, from one hundredth of a second to a minute or an hour. Some infinitesimal disturbance arrives at once, and then gradually increases in strength until it can be detected. The travelling of a wave or of a nervous impulse is entirely different from this, its arrival is more like that of a bullet,—which has either not come at all or come wholly.

The laws of the conduction of electricity along a well insulated string are precisely the same as those of heat flowing through a slab, or along a bar well wrapped in cotton wool and protected from cooling influences. If cooling is allowed, then a similar allowance must be made for the string, if the analogy is to be preserved, that is to say, the string must be allowed to leak slightly all along its course.

Moreover there is another difference. As I understand the

results attained by physiologists, the electro-motive force observed in nerve is chiefly radial in direction, that is to say, it acts between the axis of the nerve and its sheath (when it has an axis and a sheath), and barely, if at all, in the longitudinal direction. It does not seem certain that it has any longitudinal component at all, although it is transmitted in that direction. It appears to be transmitted sideways, it is set free or displayed by the agency of something which travels along the nerve, but this agency does not appear to be electro-motive in the ordinary sense; there does not appear to be a longitudinal gradient of potential; what gradient of potential there is appears to be radial, from axis to sheath, or vice versa. A stimulus applied at any point seems to make the core of the nerve positive to the outside, and this difference between them seems to excite or transmit an impulse longitudinally, which as it arrives sets up momentarily a similar difference or negativity of the outside : giving rise to a momentary change of potential which can be detected by the terminals of a galvanometer or electrometer applied to the nerve at any two points ; but the agency which travelled, and liberated the electricity so to speak, remains just as much in the dark as before[1].

(1) A few ideas as to possible modes of nerve transfer occur to a physicist, and may conceivably be suggestive to physiologists who have a vastly greater acquaintance with the facts to be explained. Without apology, therefore, I would suggest that perhaps a nerve fibre has not a conducting structure at all, but a capacity structure. It has a leakage conductance, corresponding to that of any other thread moistened with weak saline liquid, but no specific or effective nervous conductance ; but it has, I suggest, a radial capacity, as if it consisted of a series of cylindrical condensers packed end to end. A longitudinal capacity too, very likely, with all the condensers in series, provided they are not insulated from each other, but that is insignificant in comparison with the radial capacity, by reason of the enormous number of them in a small length. Such longitudinal capacity would show itself as a kind of polarization when a steady current is driven along the nerve, each condenser becoming slightly charged ; a reversed current should therefore for the first moment flow more easily ; and to an alternating current the extra polarization resistance would not be offered. I have heard that an alternating current along a nerve does experience a somewhat lower resistance than a steady current ; but if so the true conductance of the nerve fibre, considered as an ordinary conductor, would be correctly measured by the

Yet until this agency is brought to light all the physics of nerve physiology remains in a crude and imperfect state, and the physiology of special organs of sense cannot be completed; because in seeking how it is that peripheral organs receiving the energy of an external stimulus convert it into that which is appropriate to be transmitted along the nerve, we can have little hope of being able to solve this question until we know what form of energy it is which is thus capable of travelling.

That either a mechanical, electrical or chemical stimulus will excite a nerve is true enough; but the statement is no more theoretically illuminating and informing than the equally true statement that if you make a body hot enough it will emit light, without any attempt to explain what light is, or by what process it is emitted, nor why nor how heat energy (that is molecular vibrations) can be converted into light energy (that is etherial waves).

But then physicists must admit that a very short time ago this latter explanation could hardly have been given with any precision, —indeed even now it cannot be said that the details of the process are thoroughly clear or free from points of legitimate

steady current,—the current it is able to transmit when its polarization is complete,—that is when all its condensers are full. The apparent extra conductivity shown by a nerve to an alternating current would not be true conductivity, but would be a capacity effect. If R is the resistance measured by a long continued steady current; if R^1 is the resistance offered to an alternating current of frequency $p/2\pi$, and if there are n condensers in series each of *longitudinal* capacity s/k; then

$$\frac{1}{R^1} = \frac{1}{R} + \frac{ps}{nk}$$

But the individual *radial* capacity would probably be greater than s/k, say s; and the aggregate radial capacity would be estimated as

$$S = ns = \frac{n^2 \, k \, (R-R^1)}{p \, R \, R^1}.$$

I would suggest further, that on the arrival of a stimulus each nerve segment becomes momentarily charged,—negative outwards, positive inwards,—and that then it discharges into the next, charging it in the same way; and that

controversy; only steps towards an explanation have been made, and some of them have been made within quite recent years, —some within the last two years; hence it is no wonder that the more difficult question, by what means a nervous impulse is excited by a physical mechanism, or what it is precisely which goes on in a nerve and how it is excited by a mechanical or electrical stimulus to the peripheral organ, still remains unanswered.

In attempting, not to answer it but to indicate some facts which must probably be taken into account before an answer can be formulated, I find myself involved in an entanglement of recent research into the structure of matter and the nature of what has been called the ultimate atom, out of which sooner or later something is bound to emerge in the physiological direction, though what that something may be I will not attempt to predict. I will merely say that the fact that a cathode—a negative terminal —is the most active stimulus for a nerve, will be seen to derive some possible illumination, or at least to be rather suggestive, in the light of what follows.

The facts and researches to which I allude are not however as yet generally known, and possibly have not (the most recent of them) even been heard of by physiologists; so I propose to utilize the space allotted to me by an attempt to sketch the main

into the next, and so on, until the last discharges into and stimulates the muscle. The conditions for the discharge might very possibly be the dead-beat condition $L = \frac{1}{4}SR^2$.

The time-constant of each condenser would depend on the product of its resistance and capacity, and so its order of magnitude would be sR/n. This represents something like the time required to charge and discharge the condenser, with whatever electromotive force may be available in its structure: the source and seat of the E. M. F. being a matter on which I shall be silent: though the partial similarity of nerve electricity and muscle electricity, and the ready modification of muscle into an electric organ, suggest that such an E. M. F. is certainly forthcoming from live organic tissues.

The time taken to travel along a length of nerve having n condensers end to end, would therefore be of the order Rs, which could be measured as

$$\frac{n\,k\,(R-R^1)}{p\,R^1} \cdot$$

features of this new territory now being conquered for science. Preluding my account however with the proviso that some of it is held on a less secure tenure than other parts, and that though I do not wish to represent as established anything which is still liable to successful hostile attack, yet I shall represent what seems to me at present to lie in the direction of the truth, though at the same time fully admitting that hostility to some of it will be felt by some physicists, and probably by many chemists for a long time to come. For it lies on the frontier of both sciences and no doubt will form a battle ground between physics and chemistry for many of the early years of the twentieth century; just as in the early years of the present century there was a long discussion and controversy as to the acceptance or rejection of the atomic theory of John Dalton.

It is not to be supposed for a moment that because the atomic theory generally has made its way into universal acceptance, therefore every detailed view of Dalton was correct and substantiated; clearly there must be distinctions. Dalton's view of the elasticity of gases, for instance, was a statical view based on the idea of molecules at rest, each surrounded by an elastic atmosphere and so pressing outward against each other and against the sides of the vessel, thus raising a piston, or the lid of the vessel after a spring jack-in-the-box fashion. This was really no explana-

So the velocity of an impulse along a nerve would be

$$v = \frac{p \; R^{\scriptscriptstyle 1}}{n_{\scriptscriptstyle 1} \; k \; (R-R^{\scriptscriptstyle 1})} ;$$

Where nn is the number of condensers in unit length of nerve; and this velocity can be made as small as experiment requires, by postulating a sufficient value for nn.

Suppose, for instance, the resistance measured by a current alternating one thousand times a second came out one per cent less than the resistance to a steady current, and suppose the velocity of propagation of a nervous impulse was thirty metres per second, then the number of cells or condensers per centimetre of fibre would have to be of the order two hundred, provided the longitudinal capacity and the radial capacity of each were approximately equal. These numbers are quite gratuitous.

tion of elasticity at all, but it might have served as a statement of the fact of gaseous pressure, had it been true that the atoms of a gas were stationary and surrounded by infinitely expansible elastic atmospheres or repulsive forces.

But as is well known these things were not true, and gaseous pressure and elasticity are now explained, not statically at all but kinetically, as due to a bombardment of free atoms, perfectly disconnected from one another except during moments of collision. Nevertheless this is a detail, and the general doctrine of the existence of atoms is universally accepted. A lump of matter is as surely composed of atoms as a house is built of bricks. That is to say, matter is not continuous and homogeneous, but is discontinuous; being composed of material particles, whatever they are, and non-material spaces. There is every reason to be certain that these spaces are full of a connecting medium, full of ether; there is no really void space; and the question may be asked, is this ether not in a manner itself "substance"? Is it not matter in another form? To this I should reply, and I suppose all physicists would reply,—"substance" it may be, "matter" it is not. Not matter as we know it, not matter in the sense we use the term. That term is limited, I take it, to the material bodies which are built up of atoms; it does not extend to the substance or medium, whatever it may be, occupying all the rest of space. This is only a question of nomenclature, and therefore of no great importance, but that is the sense in which the terms are, here at any rate, employed. When I say that matter is certainly atomic I by no means mean that ether is atomic. I hold that ether is most certainly not atomic, not discontinuous; it is an absolutely continuous medium, without breaks or gaps or spaces of any kind in it,—the universal connector,—permeating not only the rest of space, as I have just said, but permeating also the space occupied by the atoms themselves. The atom is a something superposed upon, not substituted for, the ether, it is most likely a definite modification of the

ether, an individualization, with a permanent existence and a faculty of locomotion which the ether alone does not possess. Matter is that which is susceptible of motion. Ether is that which is susceptible of stress. All energy appertains either to matter or to ether, and is continually passing from one to the other. When possessed by matter the energy is called kinetic : when possessed by ether the energy is called potential. All the activity of the material universe is due to, or represented by, or displayed in, the continual interchanges of energy from matter to ether and back again, accompanied by its transformation from the kinetic to the potential form and vice versa.

And having asserted this, which I have said at greater length elsewhere, [" Philadelphia Magazine "]; and adding the proviso that not by all physicists is it as yet, so far as I know, universally accepted; I shall henceforward discard further reference to the ether, in this essay, and shall deal with matter alone.

Matter consists of atoms, or molecules; for present purposes there is no need to discriminate. Chemically it is convenient to attribute slightly different meanings to the two terms, but the distinction is of the easiest and most elementary character. A molecule is the smallest complete and normal unit of any substance, it consists usually of two or more atoms, though it may consist of one; and what we have to say here relates essentially to the atom.

Is the atom an ultimate atom ? Is it really and truly indivisible, is it an ultimate element or unit which cannot be split up into parts; or does the customary postulate of its indivisibility mean no more than that we have not yet succeeded in discovering a way of decomposing it; or again does it mean that if we did by any means break it up into fragments it would no longer be an atom of matter but something else ? Suppose for a moment that the atom was a vortex ring in ether, for instance, which could not be split up without destruction; the splitting up would not destroy the substance of which the ring is composed, but it would destroy

the motion which constituted it a ring, which gave it individuality; it would destroy everything which entitled it to the term " matter."

If broken up it would be resolved into ordinary ether, as a dispersed smoke ring loses its individuality in common air. A common vortex ring of air or water contains within itself the seeds of its own decease; it is composed of an imperfect fluid, possessing that is to say viscosity, and accordingly its life is short; its peculiar energy being dissipated, its vortex motion declines, and as a ring it perishes. But imagine a ring built of some perfect fluid, of some medium devoid of viscosity, as the ether is; then it may be immortal; it can neither be produced nor annihilated by known means; and it is just this property, combined with other properties of elasticity, rigidity, and the like, that led Lord Kelvin originally to his brilliant and well-known hypothesis.

In the crude form here suggested, the hypothesis has not turned out exactly true; that is to say, no one believes now that an atom is simply a vortex ring of ether, and that the rest of the ether is stagnant fluid in which the vortex rings sail about. Any quantity of difficulties surround such an hypothesis as that. Its apparently attractive simplicity is superficial. Nevertheless it is not to be supposed that every hydro-dynamical theory of the universe is thereby denied. It is quite conceivable that a single fluid in different kinds of motion—some kinds of motion not yet imagined perhaps—may possibly be found capable of explaining all the facts of physics and chemistry :—whether of biology too is a much larger question. But these hydro-dynamic explanations are a step beyond anything that I propose to discuss now. I have only said as much as this in order to make it clear that what we now go on to, even if it were completely true, must not be held to replace and negative all the attempts that have been made, and that still will be made, to account for material phenomena by the motions or strains of a perfect fluid. I may as well say however that the motions that must be postulated will have to be

of a far finer grain, the individualization on a far smaller scale, than the original vortex-atom view, which was one vortex ring for each atom, and differently shaped or tangled rings for the different elemental atoms.   If there is to be vorticity at all, it would appear that the whole ether must be full of it; it cannot be a simple stagnant, structureless, homogeneous fluid for that would not transmit light,—would not account for optical phenomena even, still less for those of static electricity and magnetism.

Unintentionally we have drifted back to the ether again, whereas I want to concentrate attention on the atom of matter. Is it indivisible or does it consist of parts?   If so, how many and what are they?   Can one of them be detached from the rest of the atom and observed?   Can the motion of a fraction of the atom be detected and measured?   Can the atom be broken up, and its constituent parts dealt with?   If different kinds of atoms are broken up will they yield fragments of different kinds, or will they all yield fragments of the same kind?   Can the fragments move at a measurable speed, and can the effect of bombardment, when they are stopped, be observed?   Are the fragments all alike, and can they be weighed?   Are they, or can they be, charged with electricity; and if so what properties do they possess when so charged?   Can an atom be charged, and if so, how?   When a current of electricity is conveyed, by what mechanism is it transmitted?   Can its phenomena be always accounted for by the transport of an electro-static charge? What is meant by the inertia of matter?   Has electricity an existence apart from matter?   What is the relation if any between a unit of electricity and an atom of matter?

All these questions appear to be capable of receiving an answer; they also appear to me to be in process of being answered; and I would not say too much about the impossibility of an answer being given to some further questions before long, but they are in a different category from these, and involve a higher order of difficulty.   The question, what is the nature of

an electric charge, for instance, is not among the questions which are in process of being answered with any certainty or with any simplicity just yet ; it will probably remain for some years yet a question and a challenge. Nor is the answer, when it comes, likely for a long time to be an easy one, such as it is possible to state in general terms and ordinary language.

The existence of an electrical charge we must assume : a charged body is a fact ; whether a charge can exist without a body is doubtful, but in any case we shall assume that the properties of an electric charge are those which we know and are familiar with by experiment upon ordinary large pieces of matter positively and negatively electrified. What are these properties ? They are best expressed, in Faraday's language, as a " field of force," a region full of lines of force, every line necessarily starting from a positive charge and ending in a negative one ; no line closed upon itself, every line two-ended, every positive charge being connected with an equal negative one ; no possibility of having *plus* electricity without *minus* electricity, any more than it is possible for one end of a piece of string to exist without the other end. This fact, the existence of positive and negative charges, we must assume too : they exist, they have opposite properties, they are like opposite aspects of the same thing, or opposite elements of one compound ; or opposite strains (as J. Larmor puts it)—a right-handed and a left-handed strain in the ether. Whatever they are they exist, and their explanation must be waited for.

The charges themselves are after all only the terminals or boundaries of the field : the whole field of force itself is the most real thing ; one cannot say that the charges are the cause of the lines of force, or the lines of force the cause of the charges, they simply co-exist. The lines of force represent a structure of some kind in the ether, they need no " matter " for their existence, they can penetrate what we call absolute vacuum, they are clearly an etherial phenomenon ; but what about their ends ? Can they

terminate except on an atom of matter? The answer is uncertain, but at any rate we can say this, that never experimentally have we *known* them to terminate except on a material body. From body to body they reach, and one of the bodies is positively charged, while the other is negatively charged. That is what, at least to begin with, we must assume as universally true.

The manner of starting such lines into existence is familiar. Any two different bodies put into contact and separated will usually be found joined by such a field of force, provided precautions are taken that the ends shall not slip or leak away back to each other during the separation process.

Once the field is established, it may be carried about; but it has gradually become clear that the field is carried *through* the ether and not *with* it; in other words the field is not really moved, it is truer to say that it ceases in one place and starts in another, that as a charged body moves about its lines of force are perpetually decaying on the side of recession, and being generated on the side of approach; continuing constant in number, so long as there is no leakage, but not possessing individuality of existence. The abandoned region of ether is relieved from strain, and the encroached-upon region sustains the strain.

This transfer of the lines of force has a singular result; a result unguessed by Faraday : a result barely explained even by Maxwell ; it interposes a certain obstacle to change of motion. It does not simulate a resistance, or friction, or force of any kind,—that would tend to bring a body to rest; but it simulates an inertia, the precise opposite of force,—a power of moving where no force acts—a property requiring an unbalanced force to change the motion, or even to stop it. But matter alone, uncharged, possesses this inertia ; the effect of any charge on it is merely to increase the ordinary material inertia or massiveness,— necessarily to increase it, whether the charge be positive or negative, showing that it is proportional to the square of the charge or to the charge and the potential conjointly ;—and the

precise value of the increase has been calculated both by Professor J. J. Thomson and by Mr. Oliver Heaviside.

Hence there is discovered a new kind of inertia, an inertia-reaction to mechanical force, obedient to Newton's second law, but not a measure of quantity of matter as we have hitherto known it. It is not proportional to mass, possibly not susceptible of weight, that is to say, it is not acted upon by the force of gravitation; and yet simulating one, and that the most fundamental of the properties of matter,—the property of inertia,—the property which is measured precisely by the ratio of any unbalanced force acting to the acceleration which it is able to produce.

Are there then two kinds of inertia: one material, the other electrical? What do we know about the material kind? Very little. It has been accepted as a property which it was vain to attempt to explain,—a property whose presence is inextricably bound up with the existence of matter, and believed to be more essential to it than gravitation. What do we know about the electrical kind? Not much, but *more*. In a sense it is intelligible, we can realize how it depends on the field of force surrounding the charge; how it is a property not located in the charge or the charged body, but depending on a modification of the ether extending all through space external to the charged body, though concentrated chiefly in its immediate neighborhood, and especially concentrated in the space between two charged bodies close together when these are opposite in sign.

That as a fact an electric current, in virtue of its magnetic properties, possessed something akin to, or which simulated, momentum, has been known to science ever since Lord Kelvin wrote that wonderful paper on "Transient Currents" in 1853; or even since Helmholtz wrote his memoir "die Erhaltung der Kraft" in 1847. But that this electro-kinetic momentum was due to a real inertia, and that the apparent inertia would not cease with the current, but would remain as a property of an electro-static charge,—a constant property, whether the charge was in

rest or in motion, just as it is a constant property of matter,—
was not at that time nor long afterwards known; possibly it was
not even suspected.

To-day the question to be asked is, whether there is any
other inertia at all? There is certainly the electrical kind,—its
mechanism is fairly and to some extent intelligible,—is there any
of the material kind? The possibility of the question represents
a curious inversion of the ancient order of ideas, but the question
is most seriously asked; though its answer is uncertain. To
Dr. Johnstone Stoney it has appeared likely that a charge can
exist without the necessary presence of a material atom as a
nucleus or resting place. Matter can exist without a charge,
why not a charge without matter? A cat without a smile, as
Lewis Carroll says, why not a smile without a cat? At any rate
he has given such an isolated charge of electricity a name—
" electron "; that means a unit of electric charge, positive or
negative, disconnected from any material body, and of which no
fractions are possible, the hypothetical ultimate " atom," so to
speak, of electricity.

But we must not be too sure that such detached charges can
exist without matter. As electrical units they are known and
measured in electrolysis, that is, in liquid conduction of electricity,
and there they are certainly associated, and inseparably associated
while in the liquid, with material atoms. The whole conveying
of electricity through a liquid consists in the convection of the
atomic charge by a travelling atom, or it may be, the convection
of an atom by its travelling charge. Atoms thus charged and
travelling are called " ions " : some of them are positive and some
negative, and they travel of course in opposite directions along a
potential gradient.

All this is familiar, and the magnitude of the ionic charge has
long been known. Known it is also that hydrogen atoms have
one such charge, oxygen atoms two, gold atoms three, and so on.
As many as six such unit charges, all of one sign, may, it is supposed,

be possessed by some kinds of atoms,—or as few as none,—but never a fraction. An ionic charge is the irreducible minimum, as it would appear, and was styled by von Helmholtz "One molecule of electricity" : every actual or possible charge being an exact multiple of this unit. Small of course it is, but not small compared with the mass of an atom ; its ratio to the atomic mass is accurately known ; this ratio, the ratio of the quantity of matter to the quantity of electricity, is called the electrochemical equivalent of the substance ; and was measured first by Faraday,—afterward with greatest accuracy by Lord Rayleigh.

Nowadays, through Dr. Johnstone Stoney, Professor Loschmidt, and Lord Kelvin, we know approximately the absolute mass of an atom ; hence we know, with equal approximation, the value of the atomic or ionic charge, in terms of what we call an electro-static unit ; and it comes out about 10^{-11} of such a unit per monad atom. All this is the a, b, c, of electro-chemistry. Why then introduce it here ? For the sake of completeness, and as a reminder to those whose physics may be a trifle rusty.

Now comes the first question :—is the atomic charge fixed to the individual atom, or can it be passed on to other atoms ? Answer :—in the liquid state the charge is certainly fixed to the atom ; there is no trace of physical or metallic conductivity ; true liquid conduction is wholly chemical or convective ; the atom travels with its charge, and at the same rate ; the two are inseparable in the body of the liquid always, whether the current pass from one liquid to another of different composition or not, provided always that no part of the liquid becomes solid, forming an insoluble precipitate. This answer is rendered possible by the careful quantitative experiments of Faraday. It was and has been several times doubted, for good reasons, but for reasons whose other meaning is now understood.

But the case is quite otherwise when the matter comes out of solution, as it must when a solid electrode is reached. Then the charge and the atom separate ; the electricity goes one way,

into the electrode and on through a wire; its quondam carrier or atom goes another way, into the liquid perhaps, or else stops behind on the electrode, and ultimately, it may be, escapes as gas or otherwise undergoes customary chemical accidents. It is not difficult to picture two or more such atoms, thus planted side by side or superposed in close contact, relieved from the similar charges which kept them asunder, combining, possibly by ordinary cohesion, either with each other or else with the electrodes to which they cling.

It is more interesting to follow the freed charge in its progress through the metal. How does it travel now? There is no convection or conveyance *per ion* here, it must either make its way between the atoms, or it must be handed on from one to another. The method of transmission is not that of a seed carried by a bird, but that of a fire-bucket passed from hand to hand. And yet not quite or not necessarily like that, for we have no certain means of individualizing the charge as we have the bucket, all we know is that the same amount is passed on; but an atom may conceivably receive one charge and pass on another of equal quantity,—provided there is any meaning in this attempt at individualization of electricity.

There is plainly a temptation to attempt such individualization when it is realized how like an "atom", in some respects, this unit of charge is. It can be had in multiples but not in fractions, there is a sort of "law of combining proportion,"—most of the arguments of Dalton for the atomic theory of matter now apply to electricity. Is electricity then atomic too? Does it also consist of indivisible portions each of definite quantity and all exactly alike? It is not wise to assert such things too hastily, but that is the appearance which facts present. Dr. Johnstone Stoney, among others, has definitely faced some of the consequences of this view of electricity and has supposed that these apparently indivisible units can separately exist as "electrons"; and Dr. J. Larmor has attempted a comprehensive mathematical

theory of the whole material universe on the basis of these electrons as strain centres in an otherwise homogeneous ether.

Anyway we must admit that such electrons, whether they have a separate existence or not,—that is whether they can exist apart from matter or whether they only represent a charge existing on a material particle of some kind,—are themselves a great deal more like matter than we might have expected. Considered by themselves they possess inertia, as we have seen, and are capable of acceleration under mechanical force in accordance with Newton's Laws of Motions.

At the same time an electron is certainly not an atom, for it is capable of being separated from an atom and conveyed one way while the rest of the atom goes the other way. It appears in fact, so far, as only another name for an ionic charge, plus the postulate of individuality and indentity. For when masked or neutralized, the electron is not destroyed but is merely brought face to face with an equal electron of opposite sign ; the distant effects of each are then neutralized until they are once more separated.

Electrolytic conduction certainly consists in the travelling together of an atom and its charge, but metallic conduction may be either the travelling of an identical electron from atom to atom, or it may be the reception of one electron and the passing on of another ; and this latter view is on the whole decidedly the more probable. Each atom receives a charge from an adjacent one, and passes an equal charge on to the one adjacent on the other side, and this process may readily be accompanied by a slight molecular motion exhibiting itself as a rise of temperature. And if, having the process of interchange of constituents in view, we contemplate what must happen at a junction of two different metals across which a current is flowing, we shall witness a curious interchange or transfusion of substance, but without change of identity, without real transmutation and without combination or alloy. This is not the place to dwell on that

aspect further : suffice it to say that the modern doctrine of the nature of the atom must have an influence on a vast number of physical phenomena, whether they occur in wires or whether they occur in nerves.

But a consideration of metallic conduction would never have given us the conception of an electron. Nor would a study of electrolytic conduction. The latter gives us the notion of an ionic charge, an indivisible electrical unit, but we find it there always associated with an atom of matter. How then have we gained the idea that it may be possibly associated with masses of matter less than the atom, or possibly with no mass of matter at all ; how have we got the notion of an electron as a separate entity ? The idea has come to different men in different ways, and we are not now concerned with any historic order; I will take the facts in any order convenient for exposition.

A few years ago Professor Zeeman of Amsterdam—one of that race with whose colonial descendants we are sadly and badly and madly at war, for these epithets apply to whomsoever the fault of origin belongs,—a few years ago Professor Zeeman discovered that the lines in the spectrum of incandescent sodium vapor were slightly broadened by the influence of a strong magnetic field applied to the flame, when examined in a spectroscope of adequate power. It was an effect that Faraday had looked for, and failed to find, because it is very minute, and the optical resources of his day were quite inadequate to show it. Nowadays the splendid diffraction-gratings of Professor Rowland of Baltimore make the demonstration (though not the discovery) comparatively easy : and the lines of the spectrum of all sorts of metals are found to be doubled or tripled or quadrupled, or even hextupled, according to the nature of the metal and the individual character of each line. Well, what of that ? The bare fact is not illuminating. No, but no fact is really bare, except in the subjective sense that we have not yet clothed it in theory. In this case the theory was ready, it was provided for it by Larmor

and by Professor H. A. Lorentz of Leyden, a brilliant mathemat-
ical physicist of the same strong race.   By these men and by Fitz-
gerald of Dublin the bearing of the new fact was quickly grasped,
as well as by Zeeman also, as shown in his correspondence with
Lorentz.   At once the measured amount of the broadening, the
distance apart of the components of the doubling, became the
means of ascertaining the electro-chemical equivalent of the
radiating matter.   Electro-chemical equivalent is a term in elec-
trolysis ; what has that to do with radiation ?   It signifies the mass
of matter associated with a unit charge of electricity.   Precisely,
but considered from the point of view of Clerk Maxwell's theory
of light it applies to a radiating body also.

In order to emit waves into the ether an electric oscillation is
necessary ; a mechanical oscillation will not do.   A radiating
atom must contain some sort of vibrating electric charge.   It may
be that the whole atom, with its ionic charge, is vibrating ; and
it may be that an electric charge is surging to and fro on an atom,
as it surges on a Hertz-conductor ; or it may be that some fraction
of the atom possesses the charge, and that this fraction only is
set vibrating, while the remainder is inert.

This electric view of radiation, which ever since the time of
Maxwell and Hertz has been in everybody's mind, is proved to
be the true one by Zeeman's phenomena, *i. e.*, by the fact that a
magnet influences the vibration, either accelerating or retarding
or otherwise complicating it ; for a magnet only so acts on an
electric current—that is on an electric charge (or charged body)
in motion.

Moreover it furnishes us with a means of determining how
much matter, or rather how much inertia, is associated with the
vibrating electric charge, for on this depends the effective
result of the magnetic influence.   How the measurements are
made would lead us too far into detail : suffice it to say that the
change in the frequency of vibration caused by the superposition
of a magnetic field of measured intensity can be quite accurately

determined from the changed appearance of a spectral line when examined micrometically ; and that when this measurement is made, in the light of Lorentz's theory, the value of m/e, the ratio of the mass carried to the charge which carries it—to invert the usual order of expression,—can be reckoned.

It could also be reckoned in electrolysis : and it would be natural to expect that the two determinations should agree. But, they do not agree. For some reason or other the electro-chemical equivalent concerned in electrolysis is something like a thousand times larger than the electro-chemical equivalent concerned in radiation. What does this mean ?

It must mean either that the electric charge whose vibrations start the series of ether waves that we call " light " is a thousand times bigger than the electrical unit or ionic charge associated with an atom in electrolysis ; or it must mean that the mass of matter associated with the vibrating electric charge is but a small fraction of the total mass of an atom. Or of course, though that may be thought unlikely, a certain proportion of both these divergencies from the expected state of things might have to be admitted.

There is nothing for it but to examine and decide between these hypotheses by quantitative experiment. But it is not an easy matter to think of an experiment that will discriminate. It is not difficult to measure the ratio m/e, but to measure either the quantity m or the quantity e is a puzzle. Can it be possible that the atom itself is stationary, and that the electric charge is oscillating to and fro over its surface by simple conduction, as if it were a Hertz-vibrator ? No, this will not do. It will not do for many reasons. The Zeeman effect would not occur if a mere conductor with an oscillating conduction current in it were put into a magnetic field. There might be some variety of that curious effect discovered by Dr. E. H. Hall (now of Harvard), but the Zeeman effect points to something more than that, it points to a real orbital motion, a motion like that of a planet or

a satellite, a motion of matter with inertia, subject to the mechanical laws of motion, and perturbed in a recognized manner by mechanical force—by the force exerted on its electrical charge by a magnetic field.   But a conclusive reason against the atomic Hertz-vibrator hypothesis was known long ago : the oscillations would be too quick.   Perhaps such oscillation may occur, perhaps not ; but anyway they would not produce *light*. X rays, or uranium rays, or some such radiation of much higher frequency, they might produce ; but from the dimensions of an atom we know that their wave lengths would be hundreds of times too small for visible light.

What remains then ?   Can it be possible that the ionic charge, in the concentrated and individual shape of an electron, is sufficiently individual and detached to be performing a vibratory excursion on its own account ?   Are we to think of the atom as having a vibrating charged tongue,—not exactly like the clapper of a bell, because it does not strike anything, but like a bead on the end of the spring of a Wheatstone's Kaleidophone,—a vibrating portion performing a definite orbit, which is perturbed by a magnetic field ?

There is this much further information to be obtained from the Zeeman effect ; the sign of the effect is such as to indicate that the moving electric charge is negative, that radiation is due to the vibration of negative electricity ; and that the corresponding quantity of positive electricity, which must be present somewhere in the molecule, is comparatively or practically stationary.

It is no new thing for negative electricity thus to show itself more mobile than positive.   Such special mobility is very familiar in the high vacuum tubes introduced and studied with such admirable results by Sir William Crookes, by Professor Hittorf and others.   In a highly exhausted tube negatively charged particles are flung off the cathode at high speed, travelling in straight lines, travelling that is to say without striking each other for considerable distance, but ready to bombard anything

introduced into their path, and either to propel it forward like the vanes of a mill, or to heat it to incandescence, or both.

Such charged and flying particles, for so Sir William Crookes conceived them to be, have attracted, under the name Cathode rays, considerable attention. They are decidedly energetic and are extraordinarily penetrative. Hertz found that they could go through a metallic partition. A sheet of solid aluminium interposed as a shutter between two halves of the vacuum tube, did not act as a shutter, but as a semi-transparent window: a decided proportion of these cathode rays went right through it, or if they did not go through they appeared to. At any rate a considerable number were shot off the hinder face of the shutter by reason of the impact of cathode rays on its front face, and these fresh cathode rays continued and preserved the properties of the old. By means of such a metallic partition Lenard became able to study these rays after they had gone through into other media: into gases at different pressure for instance; and ultimately out into ordinary atmospheric air. Across the crowded obstruction of ordinary high pressure air it was not likely that these emerging rays, the Lenard rays as they are called, could travel far; they go a few inches but they soon have to stop. Nevertheless they too are penetrative and can go through metal sheets; and can affect photographic plates or the eye on the other side and give many surprising results of a kind of shadow photography. And then the next step:—the discovery by Röntgen that the impact of the cathode rays, or of the Lenard rays either for that matter, especially if they struck a dense substance that they could not well penetrate, excited shivers of another kind altogether,—a kind of vibration or shock or quiver much higher in pitch than a source of light, a vibration which may very well consist of an electric charge oscillating by a sort of conduction on a suddenly struck or stopped atom, an electrical vibration which must occur by means of the known inertia of electric charges, a vibration which

starts those hyper-rapid etherial waves known as Röntgen or X
radiation.

That is what these cathode rays can do, but what are they in
themselves? They are certainly electrically charged, for if
caught in a hollow vessel connected with an electroscope, its
leaves will diverge with negative electricity. Are they then a
flight of negatively charged atoms? That is what most of us
thought they were; but Sir William Crookes, by an effort of
predictive genius, described them as consisting of matter in a
" fourth state " : neither solid nor liquid nor gaseous, but,—in
some other state.

Why are they not atoms? We can answer clearly now,—
for several reasons but chiefly for these two :—they move too far,
and they move too fast.

First they move too far. Atoms are big things, the thousand
millionth of an inch in diameter, and they cannot travel far with-
out mutual collisions. They are constantly colliding, even in a
very good vacuum. In ordinary air every atom strikes another
about six thousand million times a second, and it cannot travel
even a microscopic distance without collision ; its free path is
microscopic, or on the average ultra-microscopic. In a vacuum
of course it is much freer, but still it is difficult to get a vacuum
good enough for atoms on the average to travel a whole inch
unmolested; but, in such a vacuum as that, the cathode rays
would experience no difficulty in travelling without collision a
foot, or even a yard, if the tube were long enough. How
then can they be material atoms? Well, it may be said, per-
haps they have a long, free path because their motion is organ-
ized, they are all moving one way, they are not a mob but an
army, and random collisions are not to be expected. A good
answer, and one which may very likely have been responsible for
our persistent idea that the cathode rays must be charged atoms.
Still however there were some who urged,—no, they are not
atoms, they are either something etherial and not material

at all, a genuinely new kind of radiation,—or else they are electrons, isolated electric charges, flying off the cathode and flying along without any body to them, disembodied electricity, the pure spirit of electric charge.

The bare possibility made them worthy of careful study. How fast are they travelling; what is their velocity?

The experimental answer to this question is not hard. Whatever they are they represent to some extent an electric current, whether they contain matter or not they contain electricity, and they are in rapid movement, hence a magnet will deflect them. Everyone knew that a magnet would deflect them; it was only required to measure the amount of the curvature of path caused by a given magnetic field in order to be able to calculate,—what? the velocity? Well, not exactly the velocity, but the product of the velocity and the electric charge of each. Assume that the electric charge was known; assume that it was the ionic charge observed in electrolysis; assume that it was a kind of visible electrolytic procession of extraordinary rapidity that was going on in the vacuum tube before our eyes, and the calculation of their velocity was only a matter of arithmetic.

The assumption and the measurement of curvature by a magnet were both made; and the result came out gigantic,—the particles were moving with a speed unknown in matter before; a speed twenty thousand times quicker than bullets; a speed becoming almost comparable, still far short of that, but almost comparable with the speed of light, about one twentieth of it or thereabouts. How could matter move at such a speed as that? Doubtless they were under the action of violent forces in the immediate neighborhood of the electrodes, but their motion did not appear to depend on the persistence of a violent accelerating force; they appeared to move readily after the force had ceased, by reason of their own momentum. After all they might still be material atoms flung off by electrical forces at this gigantic speed. The potential gradient divided by the acceleration would

furnish a means of determining the value of their electro-chemical equivalent,—the ratio of mass to charge. Is there any way of determining this?

Perhaps it may be possible to measure their energy, or their momentum, and then in some way to gain an estimate of the mass of all the moving particles. It is not difficult to make a rough estimate of their aggregate energy, by letting them impinge say on the suitably coated bulb of a thermometer,—a thermometer acting as a calorimeter, after the fashion of Favre and Silbermann on a minute scale,—or say on the junction of a thermoelectric pile. Thus may the heat generated per minute by their impact be determined; but that only gives their aggregate energy and gives no information about the energy of each until they can be counted.

Similarly it is not very difficult to make a measurement of their aggregate electric charge. Catch them in a vessel of known electro-static capacity, and measure the rise of potential caused by them in a minute. The measurement is delicate and requires skill, but it can be done, and the idea of doing it is natural enough. But again what is the result? Only the aggregate charge; only a number which, in combination with the aggregate energy or aggregate momentum and the estimate of velocity on a certain hypothesis, will give the electro-chemical equivalent; that is to say, will give the ratio of the inertia to the charge of each particle. But that is no small thing to determine; it is of great interest. Especially in the light of the phenomenon of Zeeman it is most interesting to see whether the resulting value of this ratio will come out in agreement with that obtained in liquid electrolysis, or whether it will agree with that much smaller value concerned in luminous radiation.

The measurements have been made, chiefly in the Cavendish Laboratory, Cambridge, England, by Professor J. J. Thomson; and the result is of surpassing interest. The electro-chemical equivalent, or ratio of m to e, comes out not in accordance with

the electrolytic value, but in almost exact accordance with the value obtained by Zeeman.

The vibrating beads to which incandescent radiation is due, on the one hand, and the rushing particles which constitute the cathode rays in a vacuum tube, on the other, appear to be identical. The relationship is so close it can hardly be accidental. It can hardly be that it is only the *ratio* that is the same. In all probability both their masses and their charges are equal, each to each.

If it is an electron whose motions generate ordinary light, then it is a flight of isolated electrons that constitutes the cathode rays.

On the other hand if it is a vibrating fragment of the atom whose motions generate luminous waves, then it is a flying, isolated fragment of an atom which is flung off a cathode, travelling in a straight line through many obstacles at high speed and with a long free path, and ultimately, when stopped suddenly enough, generates the rays of Röntgen.

Either of these hypotheses is sensational. It were hard to say which is the more sensational. One involves a disembodied electric ghost; the other demands the splitting up of atoms into thousands of fragments, each with an electric charge of its own.

But there is one avenue still open to the commonplace. Perhaps after all the cathode rays are entire atoms,—perhaps the atom is vibrating as a whole, inside its molecule, in the Zeeman flame;—perhaps it is only the electric charge on each that is a thousand times too big, not the inertia that is a thousand times too small. This assumption would reconcile all the measurements, so far; if the difficulties of the high speed, and the long free path, the extraordinarily high charge, and many other difficulties more instinctively felt, but impossible to express briefly, could be met and overcome by special pleading.

There are thus three hypotheses to be decided between, not two; and the third or last mentioned is in deadly hostility to the

other two,—the other two between which there is no known means of discriminating up to the present date.

But how can a decision be come to, in respect to the third and commonplace hypothesis?   Plainly some further measurement is necessary.   The particles must be *counted*.   It is not enough to determine their aggregate energy, or their aggregate charge; we must determine either their individual energy or their individual charge, and the easiest way of doing this is to count them.

Easy to say; but how to do it?

So far I have mentioned some measurements made by Professor J. J. Thomson and his co-workers, as measurements natural to be made in a laboratory; not easy measurements,—in fact very ingenious measurements, requiring novel designs and skilled construction, and accurate thought; but in these things the Cavendish Laboratory, its professors and assistants, have never been lacking.

To devise a means of counting the particles associated with a given aggregate charge, and to execute the measurements successfully, seems to me a decidedly high flight of genius.   We in England have not been lacking in veneration for Clerk Maxwell nor in admiration for Lord Rayleigh, but I think we may say that we feel that the mantle of those extraordinarily brilliant predecessors has descended worthily on their successor; and that his researches,—those conducted by him personally with Mr. Everett's experimental assistance, as well as those supervised by him in the hands of exceptionally able disciples and students,— have brought lustre not only upon the Cavendish Laboratory, but upon the general pursuit of physical science in these islands.

I must explain how the counting is done; and for that purpose must refer to a totally different and apparently quite disconnected chapter of physical science, viz., the formation of clouds and mist.   It was shown some twenty years ago, by Mr. John Aitken of Edinburgh, that every drop of water in a cloud or mist was condensed around a nucleus, usually a dust particle.   I suppose

I may take it as known that a mist consists of water globules, rain-drops in fact only of smaller size, and that these drops represent condensed water vapor. Well, Mr. Aitken showed that vapor could only condense in presence of a nucleus, that is to say, usually upon a solid surface,—either the wall of a vessel or of some solid or liquid body. Once started into existence a drop could readily increase in size by fresh condensation ; but there was a difficulty in starting it into existence. In other words an infinitesimal rain-drop could not exist. Such a rain-drop, we know by Lord Kelvin's theory of vapor tension would instantly evaporate, no matter how moist the air around it was. How then can *any* rain-drop exist, since, it would be thought, it must be infinitesimal to start with and gradually grow? The same kind of difficulty has been felt in Darwinian evolution concerning any finished organ whose early stages must have been useless, and therefore unconducive to the survival of its possessor. There is no such difficulty about an eye, because the merest glimmerings of light must have been useful; but the difficulty is, or was, felt about the electric organ of some fishes, which could hardly be usefully destructive until well developed. The initiation of the ordinary rain-drop is now explained : it never was infinitesimal, it started condensing upon some finite foreign surface or nucleus ; for, as Mr. Aitken shows, if the damp air is carefully filtered through cotton wool so as to exclude all foreign particles, then no mist can form, the vapor can be saturated and super-saturated ; the walls of the vessel may run down with condensed moisture, but the inside dust-free space remains perfectly clear and transparent.

The nuclei in this, the ordinary, case consisted of dust particles. But now what is the result of charging the dust with electricity, what will be the effect of an electric charge upon an infinitesimal rain-drop, if such a thing for a moment existed ? The result is to check its evaporation. The rapid evaporation of a small drop is due to the curvature of its surface and its surface tension ; an

electric charge tends virtually to diminish this, it tends to cause a slight surface pressure or distending force. A charged soap-bubble, for instance, is a trifle bigger than an uncharged one; the two effects of surface tension and electric tension are opposite. Not exactly opposite, for one is tangential and the other is radial; but whereas the tangential tension, on a convex surface like that of a liquid drop, has a resultant inwards, the electric tension ($2\pi\sigma^2$) acts wholly outwards. The surface or cohesive tension of a liquid is an intense force, and even its radial component is moderately big, especially for small drops. The tension caused by a given electric charge is usually a small force, but it increases very rapidly as the body possessing the charge gets smaller. The effect of the cohesive tension varies inversely as the simple diameter of the drop. The effect of the electric tension varies inversely as the fourth power of the diameter of the drop. Hence as the drop shrinks, the two opposing tendencies necessarily become equal when it reaches a certain minute size, and then the effect of its curvature is obliterated; it behaves as if flat. Such a drop can as easily exist as any liquid with a flat surface can; and any drop smaller than that would rapidly or even suddenly grow to this equilibrium size.

The moral of all this is that no solid nucleus is after all *essential*; an electric charge will do as well. No matter how small such a charge may be it will do something; even the charge on a single atom will suffice. Hence it follows that charged atoms or ions will serve as nuclei for the condensation of vapor and the formation of mist.

It is not the atom itself that acts as a nucleus, but its charge; the atom, for such a purpose, must be regarded as infinitesimal; any perceptible, or barely perceptible, dust particle must consist of billions of atoms. A single grain of lycopodium dust contains just about a trillion, (that is a million million million). Hence, since the atom is not needed, a corpuscle will do, or even an electron,—the hypothetical detached charge alone. The ionic charge, in

other words, on whatever it is carried, will serve as a nucleus for the condensation of vapor. It will serve even better on a corpuscle than on an atom, because it is geometrically smaller,—more concentrated,—and therefore the density and the tension of the charge at its surface are higher. If its volume is one thousandth of an atom, its diameter will be one tenth, and its electric tension ten thousand times as great as the tension of an atom or ion. It acts therefore as a powerful nucleus, and if the cathode or Lenard rays are directed on an atmosphere containing water-vapor nearly saturated, some of it at once condenses and you get a fog.

Myriads of mist-globules, too small to be individually seen, are the result of supplying what we have further on called atomic fragments, corpuscles, or electrons, to clear, moist, perfectly dust-free air.

If dust is present too, so that there is already some ordinary condensation, then the addition of the charged corpuscles adds to it greatly and makes the mist much thicker. Instead of a white or light gray color it takes on a deep brown or slaty appearance, —it puts on the aspect of a thunder cloud. The experiment is easily shown by taking sparks in or near a steam jet, and looking either at the jet or at its shadow. Undoubtedly this electric condensation, superposed upon ordinary dust-nucleus condensation, is the cause of the dense and angry looking appearance of a thunder cloud.

Thus, then, we see that if we introduce cathode rays, of known aggregate energy or known aggregate electric charge, into a vessel containing dust-free, damp air, a precipitation of myriads of mist-globules instantly occurs. How many mist-globules? Just as many as there are nuclei; one mist-globule for every corpuscle, and no more. Hence, count the mist-globules and you count the corpuscles.

Many years ago, in a lecture on " Dust " to the British Association at Montreal, 1884 (" Nature," vol. 31. p. 265), I suggested that this formation of mist might furnish Lord Kelvin with another

mode of measuring the divisibility of matter, with another estimate of the size of the atom ; the idea being to weigh the total amount of solid evaporated from a bit of platinum wire, and to count the mist-globules thereby permitted to exist. The nuclei so obtained are exceedingly and surprisingly numerous but they could only give an upper limit, and probably a high upper limit, to the size of the smallest material particle ; provided, as is probable, that in this case there was no dissociation or splitting up of atoms and no electric charges to complicate the effect. But if the experiment was made on electrically caused condensation (a variety of condensation of which no one at that time knew anything) nothing ordinarily thought of as matter would be present at all, and the limit of size so obtained might turn out decidedly too low for atomic magnitude.

But how are we to count the mist-globules ? It is hopeless to try to see them individually and count them that way. It must be done indirectly. J. J. Thomson proceeded first to weigh the cloud, and then to estimate the size of its constituent spherules. Given the individual size of the liquid spheres, and given the aggregate weight of the water contained in them, the calculation of their number is only a question of simple arithmetic. Weigh the cloud ! It is a delicate operation, but it is a straightforward laboratory operation performed with a balance.

Estimate the size of each globule,—they are all practically the same size,—how is that to be done ? Here we invoke the aid of some hydrodynamical, mathematical researches of Sir George Stokes, half a century or so ago, concerning the motion of spheres through a resisting fluid. Consider a mist-drop or rain-drop falling through air ; it is obeying the first law of motion ; it is moving with steady speed under the action of no force,—just like a railway train or a ship after it has got well started. No force, that is no unbalanced force, is acting upon it. The earth is pulling it down, and air-friction is retarding its fall ; the weight and the resistance balance ; and the conditions of balance determine

its speed,— determine the rate at which it drops. But plainly its rate of fall depends on its size. If it gets bigger it weighs a good deal more and it is resisted only a little more; hence, in order again to attain equilibrium, it must move faster. On the other hand if it gets smaller it will go slower, so that still the diminished weight and the diminished resistance may balance each other. All this is obvious. What Stokes calculated, among many other things, was the exact dependence of speed on size, for a water-sphere falling through air. Given its size he could reckon its speed. Given its speed he could reckon its size. All that J. J. Thomson had to do then, after he had his cloud formed in dust-free air and weighed it, was to watch its rate of sinking. Such a mist, indeed any mist, formed in a bell-jar, is soon observed to be sinking or settling down; a clear space appears at the top, and if it is left quiet for half an hour or so, the whole space will have become clear by reason of the gravitative subsidence of the drops. It is just like powder or fine sand shaken up in water and left to settle. If the particles are of different sizes, the coarser ones will settle first, and we have the sorting process known as levigation. If they are all the same size, a clear space will appear at the top, and the rate of settling can be observed by watching the movement of the lower boundary of this clear space,—by timing the rate of subsidence of the top of the cloud.

Thus, then, the globules and the corpuscles are counted. Their aggregate mass and aggregate charge were already determined; and so their individual mass and their individual charge becomes known.

And now what is the net result and outcome of all these measurements? The result is that the charge belonging to each corpuscle is the usual ionic charge, familiar in electrolysis; but the mass of each is not the mass of an atom at all, it is a much smaller mass,—about the five hundredth part of an atom of hydrogen. The corpuscles are not atoms, they seem more like fragments of atoms; or else isolated electric charges and not

(in any other sense) material at all. They appear to have just the mass and charge of those things whose vibrations are observed in the radiation phenomenon of Zeeman ; the things whose orbital motions and vibrations emit light. Moreover the same corpuscles are obtained, whatever may be the composition of the residual gas in the vacuum tube.

All this applies to the case of the *negatively* charged bodies which constitute the Cathode rays ; it is not so easy to isolate and examine a body charged with the unit of positive ionic charge ; but I believe that J. J. Thomson is doing or has done this also, and finds that though the charge is the same, the mass is very much greater, being in fact approximately equal to the whole atom. It is probably a trifle less, or it might be a trifle more ; it can hardly be exactly the same as the mass of an uncharged atom, because one fragment, a single negative corpuscle is missing, or else it contains a single positive corpuscle extra ; but the latter alternative is not so probable. The act of charging an atom positively seems to be identical with removing a minute fraction of its mass. A negatively charged atom will probably be found to have an atomic weight in slight excess of the normal value. But none of this has been directly verified as yet, because it is not possible at present to make these measurements within an accuracy of one part in five hundred, or with anything like that accuracy. Morever, directly we use the term " weight," we are confronted with the fact that not yet have we any real clue to that astonishing fact of universal gravitation. *Cohesion* might conceivably turn out to be due to a sort of polarization or facing round of the adjacent layers of corpuscles in a pair of atoms ; but why two neutral atoms attract each other *at a distance*, and whether two isolated, distant corpuscles attract each other with any residual force above and beyond that due to their electric charges, I, at least, am at present wholly ignorant.

We will return to the result of the vacuum tube investigations. Clerk Maxwell gave it as his opinion that a fruitful avenue to

discovery lay in a study of the phenomena accompanying electric discharge in gases; and since that *dictum* a splendid series of investigations, by Crookes and Schuster and J. J. Thomson in this country, not to mention others[1]; have culminated in the present surprising discovery. The discovery that the atom is not simple but compound; that it is composed of a great number, say a thousand, of similar parts; that these parts can be isolated and dealt with, if not individually, yet separately from the rest of the atom; that each fragment or corpuscle is electrically charged, charged with the ionic charge, charged with Helmholtz's indivisible unit or atom of electricity, the very same charge that we have so long been familiar with in electrolysis;—the very same charge, but by no means the same quantity of matter. The matter associated with it and carrying it, or carried by it, is not an atom but a corpuscle, a fragment, one of the foundation stones of which the atoms are built up; the same identical fragment experimented upon by Zeeman and whose vibrations cause the emission of light.

Foundation stones of which the atoms are built up; does that mean all atoms, atoms of every kind? Are they the *same* corpuscles that go to the making of every kind of atom, are all the chemical elements built of the same identical corpuscles; only the grouping, the arrangement and the number of them being different? Why not? So points the evidence. The very same cathode rays are found whatever be the nature of the gaseous residue left in the vacuum tube. The fragments or corpuscles do not differ.

Here is Prout's hypothesis come to life again with a ven-

(1) But here a great number of others that *ought* to be mentioned: Righi of Bologna and Elster and Geissler of Wolfenbüttel (helped in their researches by American funds; the Elizabeth Thompson science fund (hurrah), and Becquerel and Carie of Paris, and Michelson of Chicago, and many others;— and a quantity of work on an entirely cognate and confirmatory subject, —the discharge of negative electricity from surfaces by means of ultra violet light, — a subject which space alone forbids my dealing with as its importance deserves. This essay does not aim at being encyclopædic.

geance! All atomic weights multiples of hydrogen? Not so,—
but multiples of something, multiples of the weight of a cor-
puscle.

Given the corpuscles, some charged positively and some nega-
tively, all otherwise exactly alike, and all with precisely the same
numerical amount of charge, and you can build up the elements.
Take five hundred of them, let us say, two hundred and fifty
of them from each set, arrange them in some unknown grouping,
and they will form an atom of hydrogen. Take sixteen times,
or rather fifteen and eight tenths times as many, and you may
arrange an atom of oxygen; possibly they will themselves natur-
ally fall into the correct grouping if you provide the right num-
ber of them. Probably the grouping of numbers slightly different
from these are not so stable, not so likely to be permanent.

We are now too much in the region of hypothesis, but when
in sight of a unification of matter such as this, a unification that
has always dangled itself before the eyes of philosophers, a trifle
of hypothesis beyond the bounds of experiment and calculation
may for a moment be pardoned.

But we will leave this region now, and returning to our atom
of hydrogen with its five hundred or so similar corpuscles, remove
one of them, remove one of the negative variety; what have we
left? We have left a positively charged monad atom of hydrogen;
a hydrogen ion. An atom charged with the ionic charge, and
amenable to electrolysis.

What shall we do with the removed corpuscle? It can be
given up to another atom, which will then become negatively
charged, unless it promptly hands on another or the same cor-
puscle to a neighboring atom; which it may or may not be able
to do. If it is able to effect that transfer, then the body to which
it belongs is a metallic conductor.

For some reason, unknown at present, it is the negative cor-
puscles which are the mobile ingredient, the mounted infantry as
it were of the corps; a positively charged atom appears to be

positively charged not by accretion of negative corpuscles so much as by difference, by loss of negative corpuscles. It has indeed then at least one unbalanced positive corpuscle to the good, and by means of its electrical attractions the whole atom can be sluggishly dragged about, but it does not show the mobility of the equally charged but far less encumbered, free, negative corpuscle. Not likely to, when it has five hundred times the mass, and only experiences the same force. Isolated *positive* corpuscles are not yet known; positive charges appear always associated with atoms of matter, but most of the activity and the excessive rapidity of electrical actions appears due to the high charge and small inertia of the negative corpuscle.

But why do these corpuscles, at least when free, possess an electric charge, and always the same electric charge? Can they be discharged? Have they anything to leave behind if they were discharged? How much of them is electric charge and how much material substance? Is there any material substance at all? Are they anything at all but electric charges?

An electric charge, we saw near the beginning of this article, possesses inertia; a corpuscle too possesses inertia; is its inertia partly electric and partly material; part due to its substance and part due to its charge? Electrical inertia we understand; in the light of electro-magnetic law it is inevitable; but what is material inertia? Is there such a thing? Are the corpuscles after all nothing but electrons? Have they any material body or substratum at all? These are questions which have not yet received an answer. The inertia of an electron, that is of (say a spherical) electric charge, depends upon its size,—its geometrical size,—the diameter of the sphere so to speak. The smaller its size the more concentrated will be the electric field near it, and the greater will be its inertia for a given quantity of charge. Make it small enough and it may have any inertia you like. Group such electrons into an atom, and the atom will have the inertia appropriate to their number. Now the inertia of an atom

is known, and the inertia of a corpuscle is known ; but the size of a corpuscle is not known. It is certainly small, but is it small enough to account for the whole of its inertia, or must a residue of material substratum be permitted ?

Is all matter resolvable into an aggregate of electric charges of opposite sign ? And does the explanation of the material universe consist in finding an answer to the question, what is an electric charge ? I fancy that Dr. J. Larmor, of St. John's College, Cambridge, England, would answer, " probably yes."

Near the beginning of this paper I set down some questions which I said were capable, or becoming capable, of being answered ; and now near the end I have set down some questions which are not yet capable of being answered. Nevertheless there are men in England, at any rate men in the world, capable of answering them ; and without further specification I believe that I have mentioned the names of most of them directly or indirectly in the course of this paper; probably, nay certainly, with omissions however. But such men, if any in authority know them, should not be allowed to waste their time in looking over examination papers, or in tutoring even able undergraduates ; the true value of their possible service should be recognized, they should not have to seek enlistment in vain, they should be utilized by an enlightened nation and set to their own proper and appointed work.

In conclusion it is not to be supposed that I have here presented an epitome of all the evidence that can be adduced in favor of a certain view of the constitution of matter. The ideas have not come upon physicists suddenly ; the ground has been prepared by many indirect hints and suggestions,—the discharge of negative electricity by light being among them. And there is other evidence not mentioned here. The facts that originally suggested the idea of an electron, for instance, have hardly been referred to ; the evidence derived from spectroscopy and a study of stellar spectra has not been so much as hinted at ; only the most

salient and strongest features of the edifice have been represented, and it must suffice to say that there is other evidence,—some appealing more to chemists, some to astronomers, some to mathematicians,—some in favor of, and some against, such theses as the composite structure of the atom, the building up of the elements, the unification of matter, and the possible unification of matter and electricity.